SCIENCE

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THE TECHNICAL APPLICATION OF MICROORGANISMS TO AGRICULTURE[1]

OUT of a period extending over several centuries, there were developed many scientific and unclassified forces which gradually but with positive progress focused in the person of Pasteur. They were often indefinite, possibly crude, and not infrequently speculative. In the mind of Pasteur they were digested, assimilated, reconstructed and confirmed, reissuing from him in an harmonious whole. When they emerged they possessed tangible form as directive principles founded upon actual demonstration and specific knowledge.

Fermentation, the great fundamental work of Pasteur, came from his hand with new life and singular pertinency. The vitalistic element advanced by him and founded so thoroughly upon experimental data fresh from his efforts became the pilot. While perhaps in error regarding details, the general truths have stood the tests of time. Pasteur's fermentation has put into the hands of every scientist, whether in the field of plants or animals, physics or chemistry, a truly basic working policy. If extended and modified, moreover, it may furnish the most satisfactory theory for explaining the relationship of many microorganisms to disease, not as the only agent, but one of several.

The comprehensive and basic ideas contained in fermentation permeate every province of practical life, and none to a

[1] "The Lower Organisms in Relation to Man's Welfare," Symposium, Soc. of Am. Bact., Sects. C and K, A. A. A. S., Philadelphia, January 1, 1915.

greater extent than the domain of agriculture.

The applications of fermentations may be followed into the management of the soil, the plants which grow therefrom, and the animals which in turn are fed by them. Microorganisms are the initial agents which work through their dynamic forces and contribute the results of their energy to the cause of agriculture and man. More particularly these activities manifest themselves in the upkeep of the soil or in soil fertility with its complications of elemental reactions, in the growth and diseases of plants, in the nutritional and pathological processes of animals, in the canning, drying, refrigerating, brining and spoliation of food, in the production of wine, beer, bread and vinegar, in the care of water supplies, in sewage disposal, in the manufacture of vaccines and serum products, in public health control, all of which make the profession of agriculture more definite and more scientific.

It is peculiarly fitting to assign to Liebig the synthetic initiative in scientific agriculture, for through him agricultural knowledge was first effectively arranged or systematized, brought out of ignorant obscurity, and placed in line for further and secure development. Although he failed to grasp the full significance of the true rôle of microorganisms in nature, he nevertheless provided the encompassing and essential knowledge which enabled microbiology to find the basis upon which to build its superstructure. In other words, he excavated and placed the stone with the cement, but it was left to Pasteur to prepare the framework of the biological building to be placed upon this foundation. Reverting to the forces which focused in Pasteur, Liebig was probably more successful in converging them than any other scientific investigator.

It is especially easy to trace to Liebig's soil studies those pioneer observations bearing on the formation of such compounds as ammonia, and nitrates in the soil, and such other facts as point the way to a utilizable knowledge of scientific agriculture. He recognized the accumulation of nitrogen in the soil, but failed to conceive, before his death, the nature of the process concerned with its accumulation, whether, as we now view it, symbiotic or nonsymbiotic. In advancing the theory that ammonia was washed from the air by the rain, he did not receive general support because it was only a small fraction of the truth. There was lacking apparently a link in the chain of needed evidence. He wandered into the present overwhelming subjects of plant and animal physiology without fully appreciating the labyrinth of scientific dangers and difficulties he was likely to encounter, but he extricated himself with wonderful tact after surveying thoroughly the entrance chambers and the bearings of the leads into the unknown. No one may have brought to light so many experimental data, demonstrated so many isolated agricultural activities as had Liebig, but they were unbounded, to a degree unrelated, and could not be carried fully and successfully to application largely because they lacked the vehicle of a consistent or logical directive principle. In Liebig's day no guiding hand led the way and this wilderness of observation remained dense and impenetrable, for causes and their consequences must include the processes involved, and all must be determined before true, intelligent and continuous progress can be made.

Pasteur, by an almost intuitive insight into the operations of nature, was the first who could with some authority suggest the possibility that nitrification may be instigated by microorganisms. This was later

verified by Schloesing and Müntz, who by inhibiting the function of bacteria by means of an antiseptic found that nitrates failed to be produced, but, without the antiseptic, nitrates formed normally. This was many years before Winogradski isolated the organisms. However, with the finding of the organisms, it became possible to ascertain the conditions under which they operate most energetically, thus establishing control. This resulted, of course, in the addition of intelligent and valuable practises. Recapitulating, therefore, for the purpose of illustrating a single scientific development and sequence over a comparatively short period of time, it may be categorically stated that Liebig recognized nitrification in the soil; Pasteur's mind and hand furnished the general principle, fermentation, and suggested that this change in soil may be due to microorganisms; Schloesing and Müntz demonstrated the truth of Pasteur's suggestion by the use of antiseptics, and Winogradski completed the task by the isolation of the organisms and the study of their nature.

No more interesting scientific fact can be found than the culmination of centuries of observations and speculation in the classical experiments of Hellriegel and Wilfart. The accumulation of nitrogen in the soil had assumed a reality, even in Liebig's time, and the value of legumes to soil fertility was mentioned by Pliny, but it remained for Hellriegel and Wilfart to relate these facts definitely through the microorganisms in the nodules of leguminous roots. Symbiotic fixation of nitrogen materialized. A new era was introduced for practise, since with the isolation of the organisms by Beijerinck two years later it became possible to demonstrate directly the absorption of atmospheric nitrogen by the nodule microorganisms and further to employ them advantageously in the inoculation of plants, until to-day many thousands of cultures are utilized in the course of a year. If our purpose were mercenary, it could easily be calculated that millions of dollars were added to the wealth of the United States without the exhaustion of any resource. Man's power has increased a hundredfold in this particular alone. It may be safely said that it has already measured to this estimate and its possibilities are still open.

Symbiotic fixation of nitrogen must not be confused with the non-symbiotic. As late as 1885 Barthelot determined the presence of microorganisms in the soil which without association or symbiosis with the plant possessed the power of accumulating nitrogen. In the soil this nitrogen appears available for plant nutrition. While this means of gathering nitrogen may appear pregnant with future inducements, as yet its values are illusive, for little headway has been made in transforming the intrinsic energy into forms of great usefulness. This should not, however, be cause for discouragement, for like the discovery of oxygen, its ramifications are its future for man. Projected applications can not be measured by a score of years, but by centuries, not by present attainment, but by future progress.

The activities of microorganisms in the soil do not stop with the decomposition of nitrogenous organic matter resulting through oxidation in nitrification and perhaps later in denitrification or in the symbiotic and non-symbiotic fixation of nitrogen, for with the fermentation of the ternary compounds there are produced such substances as carbon dioxide and other organic acids which act directly or indirectly upon the mineral constituents and in this manner furnish food for plant growth not otherwise available. Then too there are the sulphur and iron bacteria

which have a rôle to play and others doubtless whose work and values we in our ignorance do not recognize.

Soil in the light of microorganisms may be regarded as a substance having for its basis or groundwork mineral constituents of geological origin to which has been added organic matter. Through the fermentations and changes in the organic matter and the solution of mineral substances incited by microorganisms such products are formed which give to plants their existence. The mineral constituents forming the basis must be those, of course, essential to the construction of vegetable tissues, and the organic matter after decomposition such as will contribute required food. The continuity of the supply is paramount. After all the elements are present and the conditions for microbial and plant life provided, the active or operating machinery of the soil is resident in its microorganisms.

It follows also from the above—a matter of great importance to the microbiologist—that soil types are as variable as their geological formations, the mineral constituents which give them their character, and the organic substances which enter into their fertility. This variability is heightened when to it is added a consideration of the varying amounts of mineral and organic substances present. Soil, therefore, as we have employed the term, can not be interpreted from any one type or several types, but rather specific instances and specific types formed under known conditions. Soil, defined by its structural parts, unless concretely and definitely applied to some type, has no existence, but when so defined holds its physical, chemical and biological factors, harmoniously united in its mineral and organic composition.

The dairy as well as soil offers interest to the agricultural microbiologist.

In a sense it is a veritable microbiological laboratory instituted for commercial purposes. On the other hand, to the dairyman it is a great industry based upon several elemental sciences and other distinctive industries. Furthermore, it is concerned with the preparation of milk and milk products for the consumer. Microbiology is only one support in this extensive food manufacture. Our approach is microbiological and our treatment will be its interpretation from this viewpoint, which has been greatly emphasized during the past twenty-five years.

Cow's milk can not receive full approval without the vital and broad question of disease transmission from the animal at once arising. Although knowledge of the importance or extent was at first extremely meager and indefinite, growth has occurred from the time when Klein wrestled with the probabilities of communicating diphtheria through the blood and milk till the present moment which grants specific information and satisfaction in the matter of the most serious diseases. Tuberculosis has assumed huge dimensions within the memory of most of us, for it came into the limelight of popularity by Koch's discovery of tuberculin, a discovery which alone has paid for all the time and means expended upon microbiology since the days of Schwann. As an illustration of doubt and the stage of dilemma and misty ideas necessary to the decisive solution of all weighty questions, the present furnishes the milk producer and microbiologist with the "dairy septic sore throat." These allusions, however, indicate very slightly how great is the "microbiological purity" of milk as it emerges from the cow.

Then as the milk is exposed to the contaminations of the milker, the air, the utensils and the stable, or as it passes through the paths and by-paths of the milking process—the most crucial undertaking

in reality—it becomes more and more laden with dangers. In the eyes of the milk producer the drawing of the milk from the udder and passing it on to the consumer is fraught at times with insurmountable difficulties. This task is not easy for a trained, intelligent manipulator, so many and diverse are the ways of contamination. Too many who have never drawn a drop of milk from a cow under the practical conditions which surround her find it very simple to lay down regulations. To carry these into effectiveness by force against possible negligence, ignorance, indifference and even criminal wilfulness, only increases the strength of the barrier which separates the controlling and controlled elements.

Other important manipulative processes in the dairy as straining, cooling, pasteurizing, cleansing, may be readily designated as a struggle against the army of microorganisms which has been allowed to enter. This warfare is costly when it proves to be nothing more than the undoing of what has been done. It is the recognition of ignorance and conditions over which control is impossible through any plan devised by man, but it is also the award of inheritance and traditions fostered in former generations and neglected as a lowly pursuit.

In the preceding paragraphs artificially reared babes have been the indicators by which the microbial reactions are determined. We now turn to the adult who seeks security from invasions by microorganisms through the medium of milk. The ages have given to us sour cream butter, properly ripened cheese, various palatable fermented milk drinks. Sweet milk is a source of danger, but time has been beneficial in demonstrating that if milk is started with the right fermentation the element of danger is routed. Accordingly, in the knowledge and practises of the day, it is a simple matter to develop innocuous but dominating cultures of lactic or other organisms which will lend themselves to supplanting and controlling those organisms whose presence is not sought in the cream which makes the butter, in the milk which makes the cheese, in the intestines subject to all sorts of defiling and toxic substances, in milk which leads to koumiss, kephir, yoghurt and other delectable milk beverages. The taste once developed, as that which selects a fine wine, attempts to extend the local manufacture and demands for instance for a Camembert or Roquefort a broader field, for in such products are found the bouquet of a *Penicillium* and other organisms which find response even in an American palate.

The vulgar term "starter" exemplifies the Yankee adroitness in the use of words which hit. It must not be gathered that it is confined to the dairy, for it has been used for yeast in the making of bread, in brewing and wine production, in vinegar manufacture, and elsewhere. The new method employs a starter which is a known culture of microorganisms and the old method employed a starter, under different names, of unknown germ content.

Not only milk, but foods of many kinds command the attention of the microbiologist, and they all in some form concern the farmer. Whether in preservation by drying, by heating, by refrigerating or by brining and the use of preservatives; whether in fermentation leading to some useful end; whether in putrefaction or decomposition resulting in the destruction of the food with or without the production of toxic substances; or whether in those abnormal conditions instigated by disease-producing organisms calling for inspection or public control, microbial processes are involved and microorganisms, the active

agents which are to be fostered or hindered, constitute the pulsating center of effort.

The drying of some foods has been practised haphazardly since very ancient times; the value of heat has long been known to check the advance of decomposition, even long before Spallanzani in about 1770 gave to the world his experiments with the preservation of vegetable and meat infusions; King Solomon kept snow in trenches covered with bushes and leaves through the summer, that he might have it to cool his drinks; the use of chemical substances whether for physical or toxic purposes appears to be of more recent origin. Even though observation had divined relationships and established limited and crude practises, it is a simple truth that the food industries founded upon desiccation, heat, cold and chemical compounds made no headway of significance until it was found that underlying them was the directing general principle: Food would spoil if the microorganisms were allowed to develop; if they were not allowed to develop it would remain practically unchanged. As soon as Brieger was able to point out some of the toxic substances which microbial life produced, this same principle was extended to poisoning of food undergoing decomposition. It was not, however, until the relationship of microorganisms to disease was established that inspection became truly effective, notwithstanding it had been in operation from Biblical times in much the same way as the preservation of food was practised.

I ask you to consider for a moment what economic import is contained in the preceding paragraph. Conceive if you can the amount of dried food, the number of canned containers, the food consumed which has been in cold storage or refrigeration, the value of the preserved or brined products for which you as an individual are responsible during the course of the year; you will then not be surprised at the quantities necessary to stock for one trip a great ship which carries five thousand persons. Multiplying the individual capacity by 100,000,000, our country's capacity is ascertained. What does this mean in terms of the industries indicated? To this add the great reduction in the number of cases of food poisoning together with the elimination of diseases by meat inspection; then may I again ask, is it possible to grasp the full force of what has been evolved by an acquaintance with the forms, functionings and habitats of microorganisms?

It is with peculiar pride that, in passing on to other matters of weight to both microbiology and agriculture I can, incidentally, pay tribute to Professor Burrill, the venerable worker who named the cause of pear blight as early as 1883 when he had no trail to follow; and to Erwin F. Smith, who has contributed so much to the study of bacterial diseases of plants through discoveries and the organization of knowledge in this field even in the face of much German antagonism and criticism. Our national spirit may be pardoned for the moment, while realizing that there are no international boundaries for science. From this work effective methods of control have been formulated and have enabled intelligent handling of such diseases by those concerned.

No province of microbiology even from the very beginnings of this branch of science and also back through its speculative stages of development, has received greater attention or enrolled a larger army of investigators or given more important results than that which is commonly designated as medical, sanitary or hygienic. Its gifts are broader than any industry, greater than those of any profession, and they can be measured only by the limita-

tions of humanity. While pertinent to every aspect of urban life, they are equally valuable to him who finds his work in the country.

Pasteur's mind touched economic problems. As soon as he conceived a problem he projected it to its applications. Fermentation was interesting to him not only as a scientific problem, but because heavy losses were incurred every year from improper management. He was assigned by Dumas to the study of the silkworm disease, conquered it, eliminated it, and made it possible for the silk industry to succeed. He attacked anthrax because it was making ravages among the live stock of France. By his methods of vaccination he was able to control it. He became interested in rabies and in this his unique work developed a treatment which has proved successful. This taken in connection with the introduction of Lister's aseptic and antiseptic surgery unlocked the door to an exceedingly wide field of application. To comprehend it (even by one fairly familiar with it) presupposes human power in excess of that which really exists, for it implies a knowledge of nearly every walk in life. It reaches every point touched by the human hand. In the early eighties many diseases were traced to their origin, the organisms isolated and studied in the light of prophylaxis. Then infectious diseases were a nightmare; to-day we feel they are under control and we rest in the contentment of a victory. Through the labors of the workers beginning with Pasteur followed by Lister, Koch and scores of other notable investigators, the profession of medicine has grown out of its ignorant mysticism into a science; veterinary medicine has found its inspiration, and public health has become a tangible reality.

Of the total number of infectious diseases, those attacking animals form no small part. The economic importance in this respect affects not only the producer, but the consumer as well. Here as in human medicine progress is making. With the later development of serum-therapy as in the case of hog cholera, of vaccines as in the case of black leg and other diseases, there promises to be eventually a time when most of the animal infectious diseases can be either cured or prevented.

We must not forget either that we still have not extended to our rural communities the full meaning of water supply control so satisfactorily operating in cities and towns. There are those who tell us that typhoid fever is a rural disease. This can easily be understood when the conditions generally existing are known. Water supply on the farm concerns not only the farm home and the farm animals, but by its issuing from the farm through the channel of milk, the city home as well. Before improvement is assured, the farm home must adopt safe methods of sewage disposal which are open to it. With the development of these resources; with the accumulation of rural wealth; with the formation of tastes with tone, the benefits now enjoyed by urbanites must extend to the country and carry with them the sanitary and health lessons associated with a knowledge of organisms.

It is easily surmised from the foregoing that only some of the most important microbiological features of agriculture have been treated, and these subjects in a very cursory manner. Furthermore, there is evident in all assertions an attempt to depict a general agricultural development in the light of the development of a single branch of science. Lest I may conclude the paper leaving a false impression behind, I ask your forbearance while I utter a word of explanation. Agriculture is a vast and composite division made up of

many industries, founded upon many elemental scientific pursuits. Science in reality can not be divided and subdivided, but is intricately and firmly bound together so closely that one branch can not develop fully without the other. Accordingly, to grasp a truthful and comprehensive notion, the industrial and scientific growth in agriculture should be measured only through all branches of science concerned, all practises involved, and the various industries included. It is this sort of concept of science in agriculture I ask you, in my closing sentence, to seek; and not simply a view which results from a study of a component of the whole.

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AN ANALYSIS OF THE MEDICAL GROUP IN CATTELL'S THOUSAND LEADING MEN OF SCIENCE

The basis of the present study is the list of starred names in the 1906 and 1910 editions of Cattell's "American Men of Science" representing individuals who are engaged in teaching or research in medicine or who, though occupying other fields, are directly or indirectly advancing knowledge in the medical sciences.

The analyses, presented for the most part in tabular form, have been made with the object of determining

1. The principal field of activity of each individual.
2. The overlapping of different fields of activity.
3. Nativity.
4. Age.
5. Sex.
6. Education as represented by degrees.
7. Education as represented by institutions.
8. Post-graduate study.
9. Service in one or more institutions.
10. Present distribution with rank.
11. Lapse of time between degree and full professorship.
12. Change of field of activity.
13. The clinician's position as an investigator.

It is true that the entire number of individuals is too small to allow far-reaching conclusions to be drawn. Medicine in this country is, however, undergoing so many changes—changes which began about twenty-five years ago and will doubtless continue—that it seemed advisable to analyze, for future students of medical education and medical progress, the conditions as represented in Cattell's editions of 1906 and 1910. The trend of these changes and the influence of the development of the medical sciences can be traced even in the first edition and markedly in the second, by separating the older group of men, limited to chemistry, anatomy, physiology and pathology from the younger group representing, in addition to these, bacteriology, physiological chemistry and pharmacology. In the absence, however, of definite tables of earlier periods, it is difficult to draw comparison from the first edition, except such as are possible on the basis of age. If one had tables for, say 1890 to 1895, the period representing the beginning of the rapid development of the laboratory side of medicine in this country, the analysis of 1906 and 1910 would be of greater value. Still, it is hoped that the present study will preclude such regrets on the part of some student of medical education who wishes in 1930 to analyze the advances during the period of twenty years preceding his study.

The basis upon which Cattell selected the names for "American Men of Science," as well as his method of selecting the thousand leading men, are too well known for repetition. It must suffice to state that in the first edition are the records of 4,000 men and women and that the second edition was enlarged to include 5,536. The directory is essentially a list, with short records, of individuals working in the natural and exact sciences, and it is presented as "a fairly complete survey of the scientific activity of a country at a given period." Cattell's object in preparing the special list of a thousand leading men was to secure a group for the scientific study of the "conditions on which scientific research depends and so far as